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Variability of Arundo donax growth in dry-farming as a function of soil properties

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Abstract

Arundo donax L., commonly known as giant reed or arundo, is a perennial rhizomatous grass that has been studied since the decade of 1980 for bioenergy. In the Mediterranean region - characterised by dry and hot summers- arundo is usually grown with the support of irrigation. However, there is evidence that this plant species can tolerate dry-farming conditions once the crop is fully established. In this work the variation observed in plant growth of a 5-year-old arundo crop when the management changed from irrigated to dry-farming, is assessed. The hypothesis underlying this work was that punctual variations of soil properties might be responsible for the differences observed in plant growth.

Keywords: Arundo, energy crops, biomass yield, soil properties, bioenergy

1 Introduction

Arundo donax L., also known as giant reed or arundo, is a perennial rhizomatous grass widely spread in many temperate areas of the World. This plant species exhibits stiff canes over 3 m high, that have been used since ancient times for many different applications, like as support for climbing plants or for vines, for woodwind instruments or flutes, walking sticks and others. Several attributes –i.e. perennial rhizomatous, vigorous growth, hardiness, pest resistant, competitiveness, high biomass productivity- make this plant species very interesting to researchers. On the one hand, it may behave as an invasive species in natural riparian ecosystems (Dudley, 2007)]; on the other hand, it is a promising energy crop for biomass production (Pilu et al. 2012).

Giant reed has been studied as an energy crop in Europe since the decade of 1980. Relevant contributions to the knowledge of the potential of arundo for biomass production have been made [Lewandowski et al, 2003, Angelini et al, 2005, Cosentino et al, 2006]. Biomass production depends on several factors, mostly crop age, plant density and hydric conditions. The same as other perennial grasses, like miscanthus or switchgrass, yields are low in the first year of cultivation but they increase sharply in the following years provided that crop conditions are good. In Mediterranean environments, the productivity of arundo has been assessed mostly in irrigated conditions.The potential yield (small plots, non-limiting water conditions, South Europe) has been estimated at about 100 t dry matter a year (Christou et al. 2002). In large fields, yields about 25 t dm/ha/y seems realistic (Curt et al 2013).

In its wild state, arundo thrives along river banks and creeks, but it can also be found in marginal lands, on field ridges or on roadsides (El Bassam & Dalianis, 2010) of dry sites. Giant reed shows a clear preference for moist soils but its natural distribution also suggests that it can tolerate some degree of water stress. However, few authors have studied the effect of water deficit on biomass productivity of arundo. In a hilly interior area of Sicily (Italy), Mantineo et al (2009) evaluated the effect of two different irrigation treatments (75 and 25% of ETm restoration) for 3 years; afterwards, in the 4^{th} and 5^{th} years, no irrigation was used. They reported 25.4-35.8 t dm/ha/year for the 2^{nd} and 3^{rd} year in the most stressed treatment (25% ETm) vs 36.9-41.8 t dm/ha/year for the 75%ETm. They found that the decrease of biomass yield after the 3^{rd} year of cultivation (change to rainfed conditions) was small; the recorded biomass productions were: 34.5-27.5 (25%ETm, 4^{th} and 5^{th} year) and 35.4-26.5 t dm/ha/y, (75%ETm, 4^{th} and 5^{th} year).

This work addresses the interaction between the effect of water regime and the effect of soil properties on biomass production of giant reed grown in central Spain. Rainfed conditions experienced by an energy crop of giant reed in its 6^{th} growing cycle led to great growth variability. We hypothesized that variation of soil properties might be responsible for the differences observed in plant growth.

2 Materials and methods

2.1 Field experiment

The field experiment was located in the municipality of Alcala de Henares (Madrid, Spain), specifically in the experimental farm 'El Encín' of IMIDRA (Instituto Madrileño de Investigación y Desarrollo Rural, Agrario y Alimentario), at latitude 40º31'12" N and longitude 3º18'13" W. Soils at 'El Encín' can be very different (Rhodoxeralfs, Haploxeralfs, Xerochrepts, Xerofluvents, Xeropsamments, USDA soil taxonomy), with a wide range of textures (from sandy to clay) and with presence (and absence) of limestone. The climate is Xeric Mediterranean, sub-type Mild Meso-Mediterranean (Mauri, 2000). Six-year means (2007-2012) are: 13.7ºC mean temperature, 63.2% relative humidity, 1.7 m/s wind speed, 16.5 MJ/m^2 global radiation, 400.3 annual rainfall and 95.6 mm/month ETP (Monteith).

Prior to planting, the soil was physically prepared and a drip irrigation system was installed; the mainline crossed the field by the middle, therefore the drip tubing was connected in both sides (2 x 65 m to lay 110 m irrigation line) of the mainline. Nine clones of *Arundo donax* were established in plots of 110 x 7 m each (1.6 x 1 m planting frame) from rhizomes in June 2008; in order to assure crop establishment, drip irrigation was provided as needed. The first harvest was carried out manually in March 2009. In the production years, the growing season extended approximately from mid March (sprouting) to mid October (senescence of the aerial biomass). Harvesting was performed every winter (February-March). Irrigation was provided during the dry season, from June to September, until 2013. In 2013, the crop was maintained rainfed. During the 2013 growing cycle, spots with poor plant growth and good plant growth were noticed and knowing that the field included different types of soil, it was made the decision that the relationship between soil properties and arundo growth should be studied.

2.2 Samplings

Soil and plant samplings were performed in September 2013 according to the following experimental design:

2 clones x 2 degrees of plant growth x 2 replications.

Where:

Clones: clone no. 9 and clone no. 7

Degrees of plant growth: Poor growth (P) and good growth (G)

Replication size: aerial biomass grown over 1.5 m^2 and soil sampled at 30 cm depth in the same sampling area.

Parameters studied in biomass samples: number of shoots, fresh and dry weight of aerial biomass, biomass partitioning and dry matter content.

Parameters studied in soil samples: pH and electrical conductivity (EC) in extracts 1:2.5 soil/water; carbonate content (measured in calcimeter); nitrogen content (Kjeldahl method); organic matter (Walkey method); available phosphorus (Olsen method); calcium, magnesium, sodium and potassium as extracted in AcNH4; clay, silt and sand (Boyoucus method). All procedures followed the official methods by MAPA (1994).

3 Results and discussion

Meteorological data recorded during the experiment period (January to September 2013) are given in Figure 1 and Table 1. Total precipitation was 259.5 mm while the potential evapotranspiration was 1066.9 mm showing that there was water déficit at this site. The dry period extended from June to September and coincided with most of the growing season of arundo.

Mean results obtained for biomass samplings are shown in Figure 2 and Table 2;. Highly significant differences were found between spots of poor and good growth, for the variables of yield (fresh weight and dry weight of biomass and canes per m^2), but not between clones, over the whole experiment. Within a clone, differences between spots were significant as well.

Table 2 shows the mean values of soil analysis. The variation found within a type of spot was higher than within the pooled samples suggesting that soil properties were not responsible for the variations found for plant growth; in other words, no relationship between soil properties and growth types could be established.

Findings of this work suggested that a new hypothesis should be proposed to explain the differences found in the growth of arundo. The distribution of the spots with good plant growth showed that they were irregularly distributed around the mainline of the irrigation system, then it was related to the events happened in 2012. Harvest demonstration activities performed in January&February 2012 resulted in damages to the irrigation system (Curt et al. 2013). Drip tubing was partly replaced with no pressure compensation drip tubing on 12th June; while testing the system, the mainline broke up and discharged a large amount of water. Plants growing in the nearby could have taken advantage of that event and accumulated more carbohydrate reserves in the underground plant parts, which would have helped arundo to grow more vigorously in the following season, when the crop was grown in rainfed conditions. This could be consistent with the results by Mantineo et al (2009), which found that changing from 75% ETm irrigation to rainfed conditions from one year to another implied only a small decrease of biomass productions in the first year of dry farming.

4 Conclusions

Results from this work did not support the initial hypothesis that soil properties were responsible for the differences observed in plant growth of giant reed after the crop management was changed from irrigated to dry farming. A new hypothesis was proposed by which the degree of growth attained by arundo plants in a season would determine their resilience to water stress in the following season.

5 Acknowledgements

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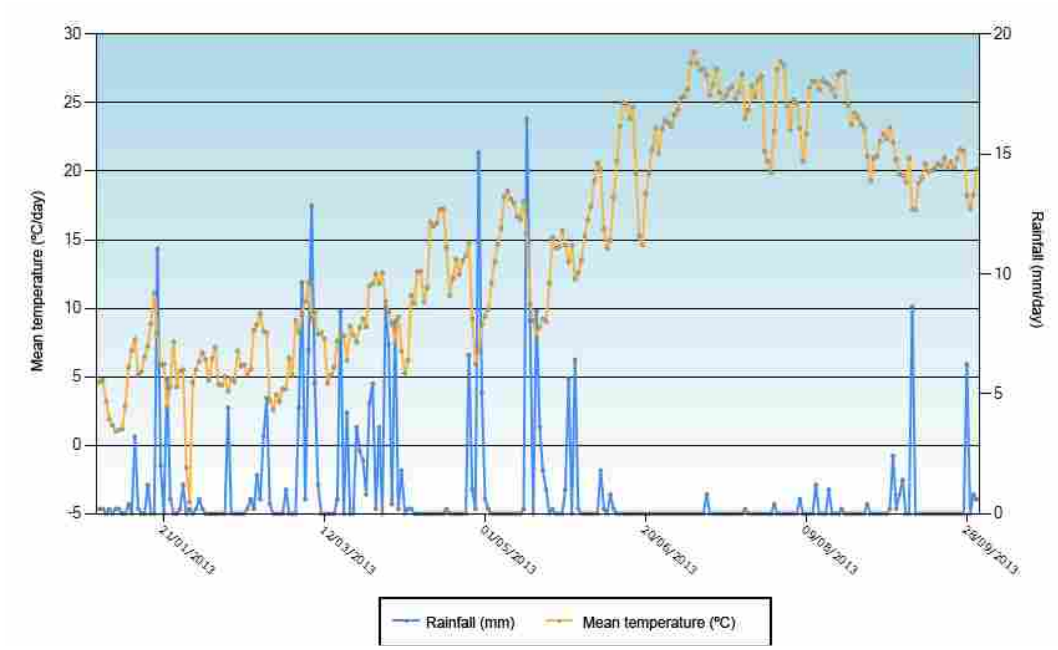

Figure 1: Daily records of temperature and rainfall. Meteorological station at 30N 457867,4473610; 604 m a.s.l. Source: Ministry of Agriculture, Food and Environment of Spain.

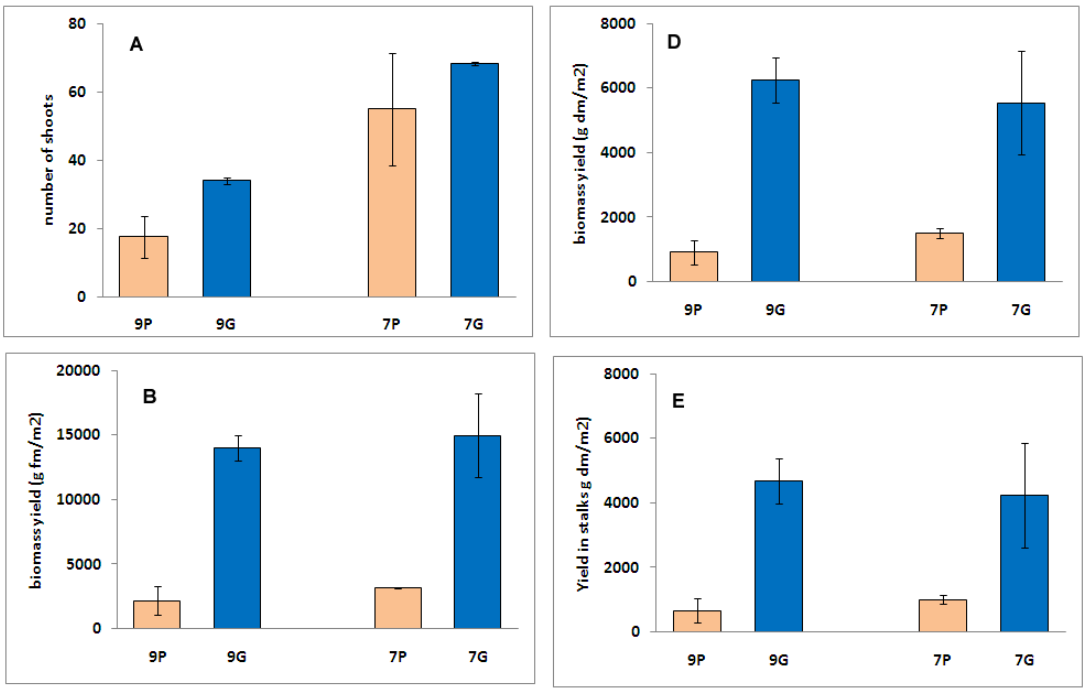

Figure 2. Number of shoots (A), biomass yield in fresh matter (B) and dry matter (C) and yield in stalks (E) for clones 9 and 7 in spots with poor (P) and good (G) growth.

Table 1: Mean temperature (tm), maximum temperature (Tmax), minimum temperature (tmin), relative humidity (Hr), wind speed (Wsp), global radiation (Rg), precipitation (pp) and potential evapotranspiration (ETo) during the period studie in this work.

Month	t_m (ºC)	T_{max} (ºC)	t_{min} (ºC)	H_r (%)	Wsp (m/s)	Rg (MJ/m^2)	pp (mm)	Eto (mm)
Jan	4.5	17.3	-5.5	79.3	2.1	7.1	27.1	27.4
Feb	5.7	15.5	-4.3	69.0	2.5	10.5	17.9	45.7
March	8.7	16.5	-4.0	75.7	2.5	11.7	86.0	61.0
Ap	11.4	27.0	-2.3	65.3	2.4	19.4	46.0	96.0
May	13.6	26.4	1.8	62.0	1.8	24.1	53.9	131.5
June	20.4	34.6	4.9	45.3	2.2	28.1	3.0	189.1
July	25.7	37.0	9.1	38.3	1.8	27.6	1.4	210.2
Aug	24.6	37.6	9.9	40.7	1.7	24.3	3.4	183.8
Sept	20.3	32.6	8.8	53.3	1.6	19.1	20.7	122.2
Jan-Sept	15.0	27.2	2.0	58.8	2.1	19.1	259.5	1066.9

Table 2: Dry matter content (% dm) of leaves, stalks and biomass, and biomass partitioning (w/w, dm basis) in leaves (% leaves) and stalks (% stalks) for clones 9 and 7 in spots with poor (P) and good (G) growth.Mean values $\pm$ std.

ID	%dm Leaves	% dm stalks	% dm Biomass	% Leaves (dm b)	% stalks (dm b)
9P	57.9±8.5	39.7±3.5	43.3±4.2	26.9±0.9	73.1±0.9
9G	43.2±6.6	45.2±0.3	44.6+2.0	25.1±0.6	74.9±0.6
7P	47.4±5.3	37.9±0.2	47.4±5.3	33±2.8	67.0±2.8
7G	34.1±2.4	37.6±3.3	36.7±2.8	22.5±6.8	77.5±6.8

Table 3: Mean results of soil analysis and coefficients of variation (cv) in percentage).

	Pooled Mean	cv (%)	Poor growth spots	cv (%)	Good growth spots	cv (%)
pH	8.1	1.5	8.2	1.9	8.1	1.8
EC (dS/m)	0.3	29.9	0.2	16.7	0.3	37.0
$CO_3^=$ (%)	1.1	49.8	1.0	71.2	1.2	34.2
N (%)	0.1	6.0	0.1	6.7	0.1	0.0
OM (%)	1.2	11.0	1.1	13.3	1.3	8.9
P (mg/kg)	12.8	17.7	14.5	16.4	11.0	7.4
Ca (mg/kg)	1897.3	13.0	1895.5	15.7	1899.0	15.1
Mg (mg/kg)	370.3	31.7	361.3	32.6	379.3	35.1
Na (mg/kg)	61.4	42.1	66.0	42.8	56.8	62.1
K (mg/kg)	141.0	23.3	166.8	14.0	115.3	18.8
Clay (%)	36.1	8.6	34.5	5.9	37.7	8.6
Silt (%)	29.4	14.9	31.9	9.9	26.9	15.9
Sand (%)	34.5	5.4	33.6	3.7	35.5	3.5